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THE MAGNITUDE OF THE ELECTRICAL FIELD IN CAVITIES FORMED BY SUPERSONIC CAVITATION OF A LIQUID

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A number of authors have connected the supersonic oxidizing effect with the development of local electrical fields in bubbles and cavities formed by the cavitation of liquids. Ya. I. Frenkel' (1) presented a theory of the development of these electrical fields. This theory regarded the formation of a charge on the walls of a cavity as the result of irregular distribution between the walls of the cavity of ions which were originally in the volume of the cavity. If one imagines a cavity originally developing in the form of a thin lens with a sectional area S and a thickness δ, then the average number of ions of each polarity striking one of the walls of the cavity is equal to $\frac{1}{2}\delta SN$, where N is the number of dissociated molecules per unit of volume. If $\delta^{1/2}$ of the order of the distance between adjacent molecules ($4 \cdot 10^{-8}$ cm), then, according to Frenkel', the ions are distributed between the walls of the cavity independently of one another. The average square of the charge forming on the walls of the cavity as a result of fluctuations in the distribution of ions is equal to

$$\overline{q^2} = \varepsilon^2 \delta S N,$$

where ε is the charge of the monovalent ion. Hence the voltage of the field within the cavity is equal to

$$E = 4\pi \frac{q}{S} = 4\pi \varepsilon \sqrt{\frac{\delta N}{S}}$$

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Let us imagine a geometric plane within the liquid dividing it into two parts. As a result of the presence of fluctuations in ion concentration, the equality of the number of oppositely charged ions observed for the liquid as a whole will not be observed at any given moment for its separate parts. Therefore, the parts of the liquid on both sides of the plane in question at any given moment will have surpluses of charge, opposite in polarity but equal in magnitude. The same thing will take place for any geometric plane within a liquid, along which a discontinuity occurs on cavitation. This charge of the parts of the liquid contiguous to the plane of discontinuity also forms the charge on the walls of the cavity developing upon cavitation. The magnitude of this charge should not be connected with the volume of the cavity which develops. It may be calculated by a method developed earlier by the author in a work devoted to the fluctuations of the charge density in solutions (2).

For simplicity we shall examine the plane of discontinuity. Let us divide the part of the liquid contiguous on both sides to the plane of discontinuity, along with the parallel planes of area S with the coordinates X_0, X_1, ..., X_y, ..., X_m, $X_m + 1$ into the series of layers of thickness dx. The work of formation of such a distribution of ions, so that there is a charge $e_0 \mathcal{E}$ in the layer between x_0 and x_1, and a charge of $e_1 \mathcal{E}$ in the layer between x_1 and x_2, etc., is equal to

$$F = (e_0^2 + \ldots + e_m^2)\frac{KT}{2v} + \frac{4\pi \mathcal{E}^2}{DS}\Big[e_0 e_1 (x_{m+1} - x_1) + \ldots$$

$$\ldots + (e_0 + \ldots + e_{m-1})e_m(x_{m+1} - x_m) + \frac{e_0^2}{2}(x_{m+1} - x_0)$$

$$+ \ldots \ldots + \frac{e_m^2}{2}(x_{m+1} - x_m)\Big],$$

where the first term represents the osmotic, and the second, the electro-static work, $V = mNS\,dx$ ($w = pz_+^2 + qz_-^2$ for the dissociation of molecules of type $A_p + B_q$); D is the dielectric constant.

The average square of the charge in the volume of liquid on one side of the plane of discontinuity X_g is equal to

$$\overline{\sigma^2} = \mathcal{E}^2 \overline{(e_0 + \ldots + e_f)^2} =$$

$$= \mathcal{E}^2 w_0 \int_{-\infty}^{+\infty} \ldots \int_{-\infty}^{+\infty} (e_0 + \ldots + e_f)^2 \exp\Big[-\frac{F}{KT}\Big]de_0 \ldots de_m.$$

As was shown in the previous work (2), this expression may be reduced to the form

$$\overline{\sigma^2} = \mathcal{E}^2 \int_0^{x_f} wNS \exp\Big[-2\int_x^{x_f} 2\pi NS(C-B)dx\Big]dx,$$

where $C = \frac{4\pi \mathcal{E}^2}{DKT}(x_{m+1} - x)$, and B is determined by the differential equation $dB/dx = 2\pi NS(C-B)^2$ with the initial condition $B = 0$ when $x = x_{m+1}$.

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Inserting the alternate $L = x_{m+1} - x$, we obtain

$$B = \frac{1}{2 \omega NS} \left[x^2 L + x \frac{1 - exp(2xL)}{1 + exp(2xL)} \right],$$

where x is the Debye inverse radius of the ionic atmosphere. Therefore

$$\overline{\sigma^2} = \epsilon^2 \int_{L_g}^{L_0} \frac{\omega NS[1 + exp(2xL_g)]^2 \, dL}{exp[2x(L_g - L)][1 + exp(-xL)]^2} =$$

$$= \frac{\epsilon^2 \omega NS}{2x} \frac{e^{-2xL_g} - e^{-2xL_0} - e^{-2x(L_0 - L_g)} + 1}{e^{-2xL_0} + 1}$$

Since $x_{m+1} - x_g = L_g \gg x^{-1}$ and $x_g - x_0 = L_0 - L_g \gg x^{-1}$, then

$$\overline{\sigma^2} = \frac{\epsilon^2 \omega NS}{2x} \qquad (2)$$

For a mono-monovalent electrolyte, $\overline{\sigma^2} = \epsilon^2 NS x^{-1}$ and

$$E = 4 \pi \epsilon \sqrt{\frac{N}{Sx}} \qquad (3)$$

Formula (3) is distinguished from (1) by the fact that the radius of the ionic atmosphere enters it instead of the thickness of the elementary cavity discontinuity. The calculation made is correct only under the condition $\sqrt{S} \gg x^{-1}$; otherwise in the expression for the electrostatic component F one cannot ignore the marginal effects at the edges of the cavity discontinuity.

Magnitude $\overline{\sigma^2}$ of Formula (2), as might be expected, corresponds to one-half of the average square of the fluctuation of the charge in a cylinder isolated within the liquid; in this cylinder the linear dimensions of the cross section are great in comparison with the height, and the height is great in comparison with x^{-1} (3).

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